NL-NS-FFAG Gantry Development

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Outline

- NL-NS-FFAG: motivations and background
- Assumptions about the gantry
- Zero-chromaticity algorithm
- Gantry design
- Tracking results
- Conclusions and future plans

Motivation and background for NL-NS-FFAG

- The scaling law provides the non-perturbative zero-chromatic solution.

- There must exist zero-chromatic solution outside this principle.

- It does not obey the similarity of orbits.

- There exists no underlying theory.

- The solution may be found within certain energy range by
using numerical search for a multipole expansion ->
PAMELA team did that starting from the scaling solution and breaking it.

- It may be justified by performance (smaller orbit excursion,
isochronicity, easier magnet construction).

Let’s try to design proton gantry based on NL-NS-FFAG method (work in collaboration with P. Posocco, G. Walton, P. Holland, M. Aslaninejad)

Assumptions:

- to use NNS-FFAG
- to use only positive bends at the central orbit
- to use SC magnets with modest fields.
- to make identity transformation in phase space for a broad momentum case (100-200 MeV for pediathric case)
- make the aperture small -> very strong focusing needed
- Use radius of ~3m -> can be made smaller

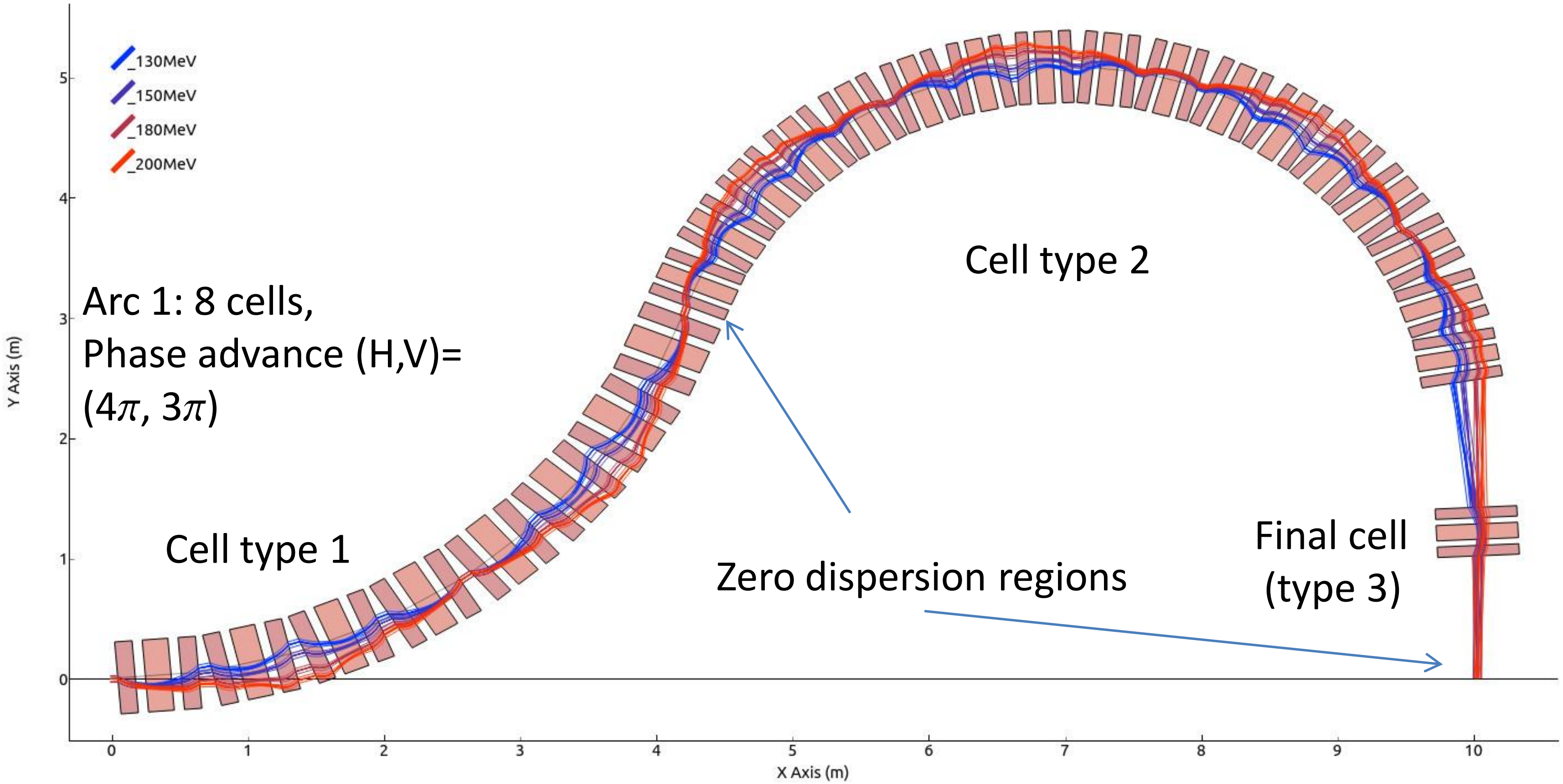
Assumptions for the zero-chromaticity algorithm

• Rectangular magnets (robust, easy case for superconducting designs).
• Multipole expansion up to octupole (decapole in some cases)

•Matching example: tunes for 3 energies (central and $\pm\Delta E$), orbit at 2 symmetry points of the cell (8 parameters)
• Degrees of freedom for triplet (2 dipoles+ 2 quads, +2 sextupoles + 2 octupoles =8)
•Sometimes decapole included.

Gantry and its orbits (size enlarged)

Arc 2 (including the final cell: 17+1 cells,
Phase advance (H,V)=(4π,2π)



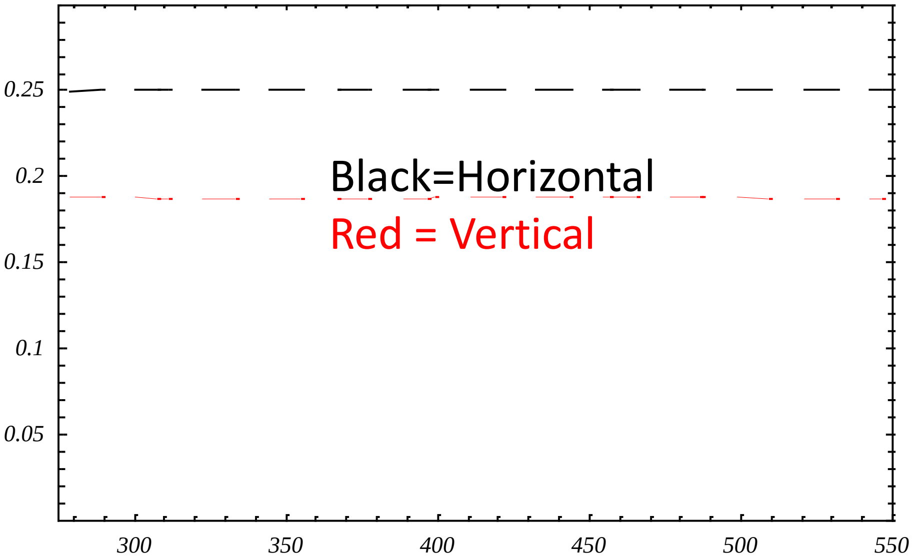
Orbit similarity is not present!

Tracking in PiZgoubi

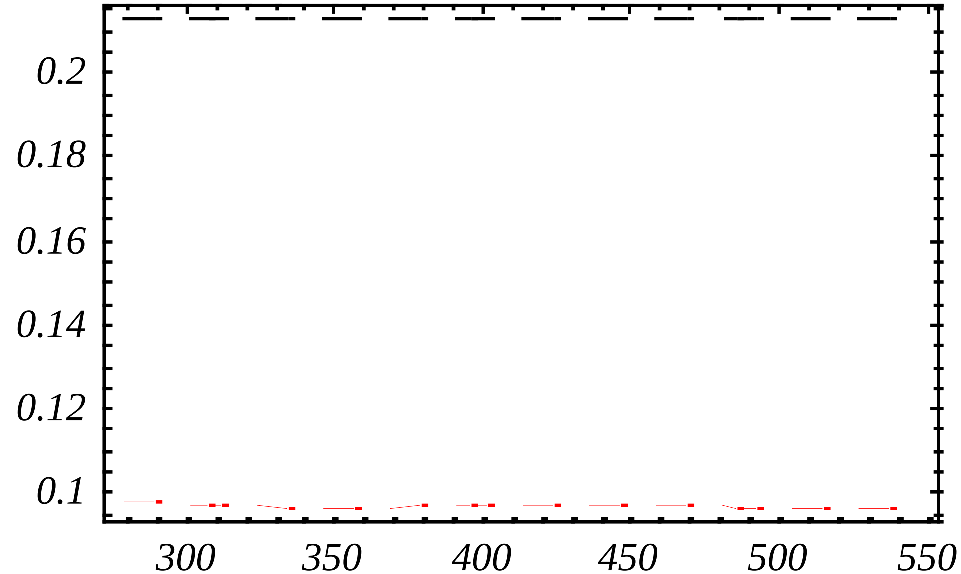
Tunes per cell, matching

Tunes/cell

Cell 1



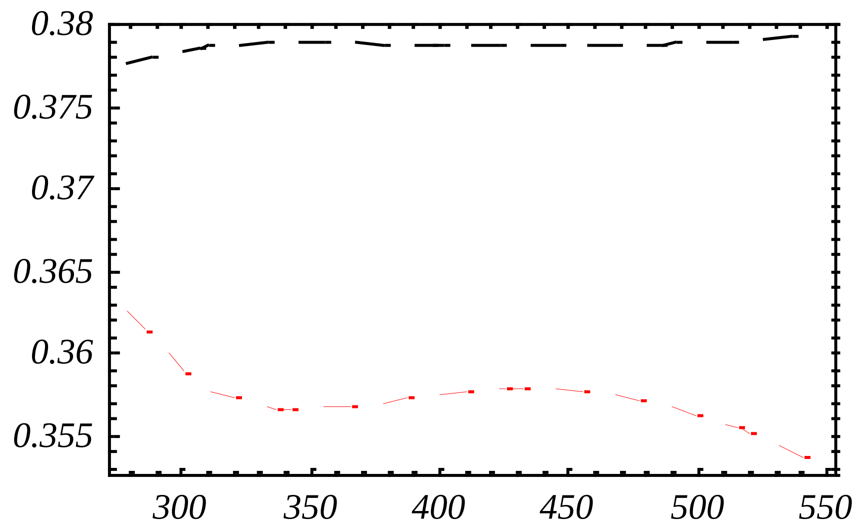
Cell 2



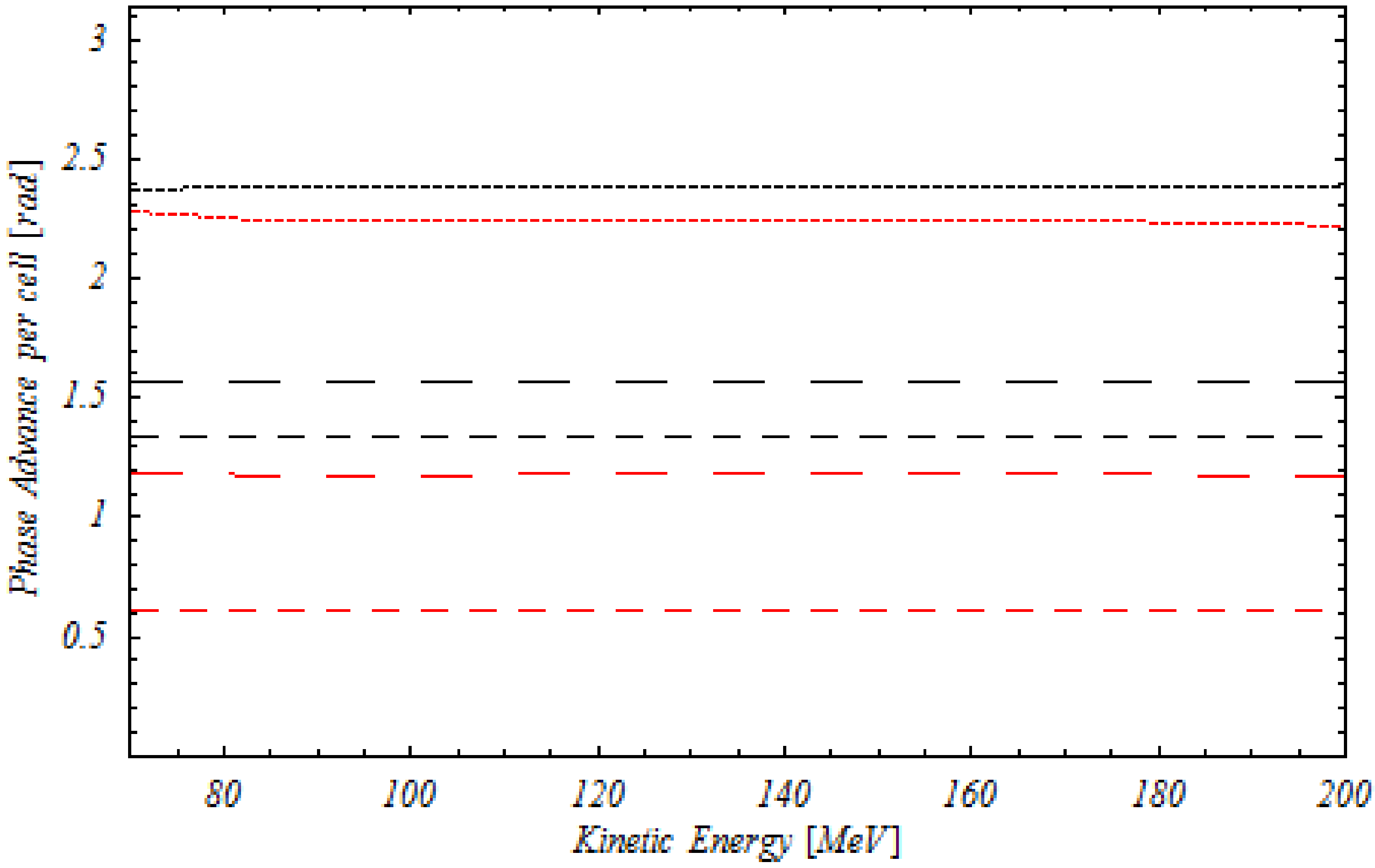
Cell 1

Equivalent muon energy range

Cell 3, final cell

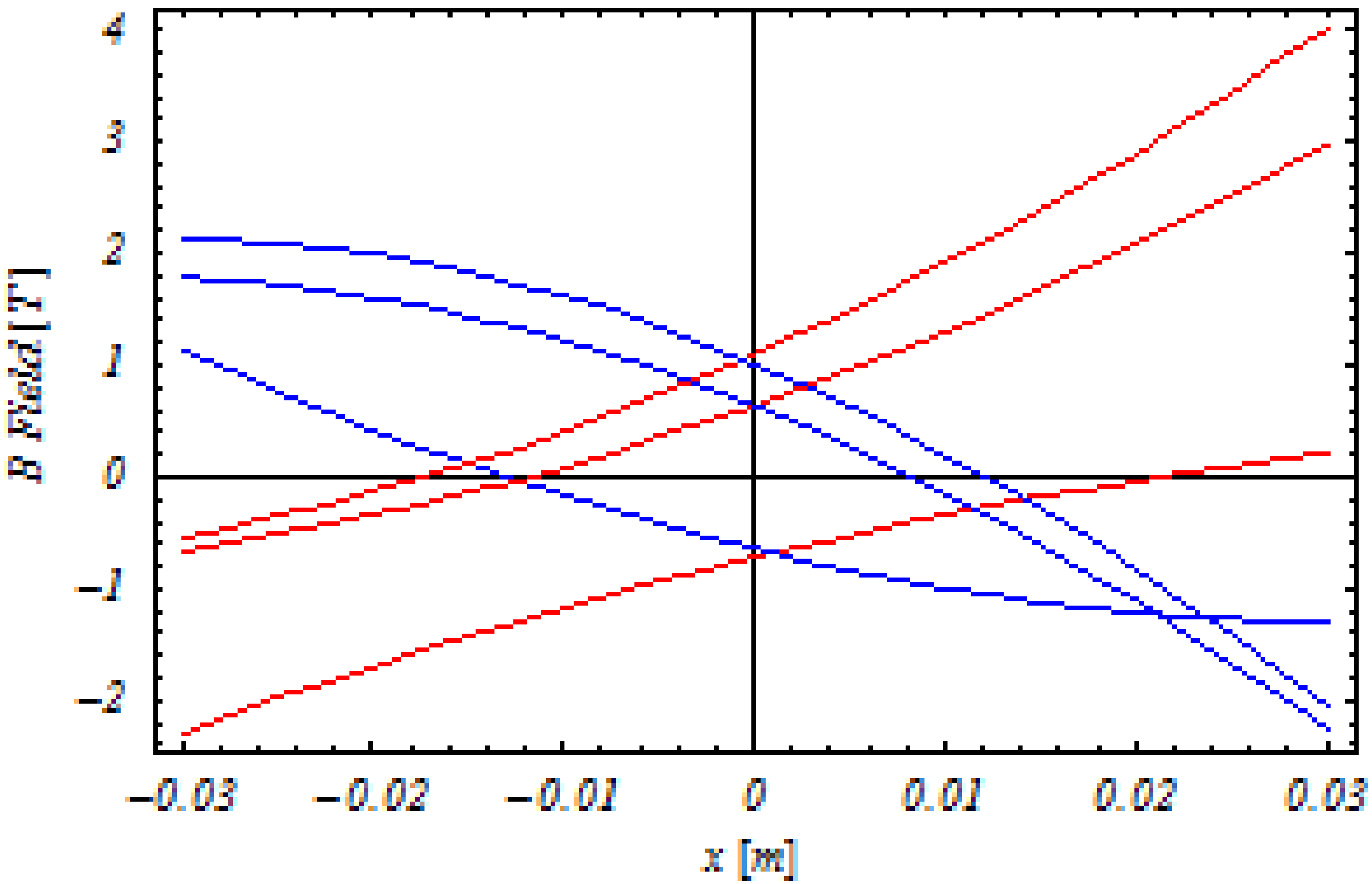


Summary of tunes



Now in proton kinetic energy!

Magnetic field in the magnets all cells



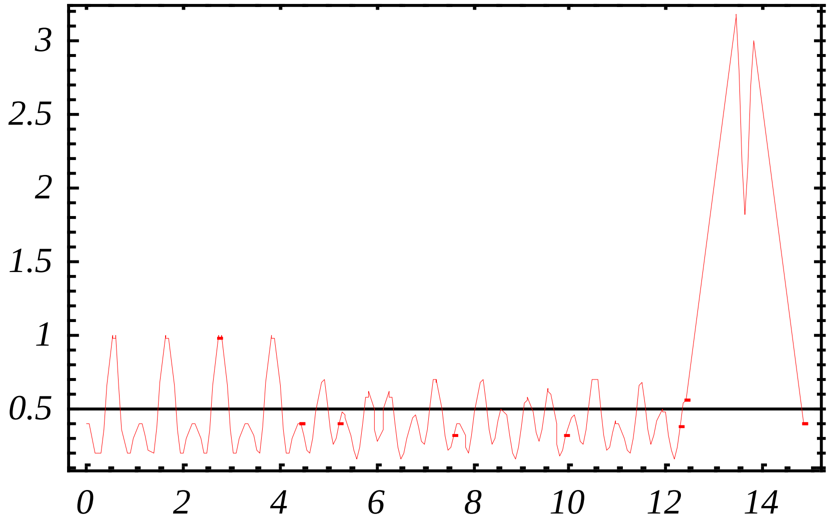
Scaling condition is broken!

Magnet dimensions used

- Magnet lengths 8.7, 9.5, 13cm
- Magnet aperture ~6cm
- Distances between magnets ~5, 6.5,7.5, 10 cm

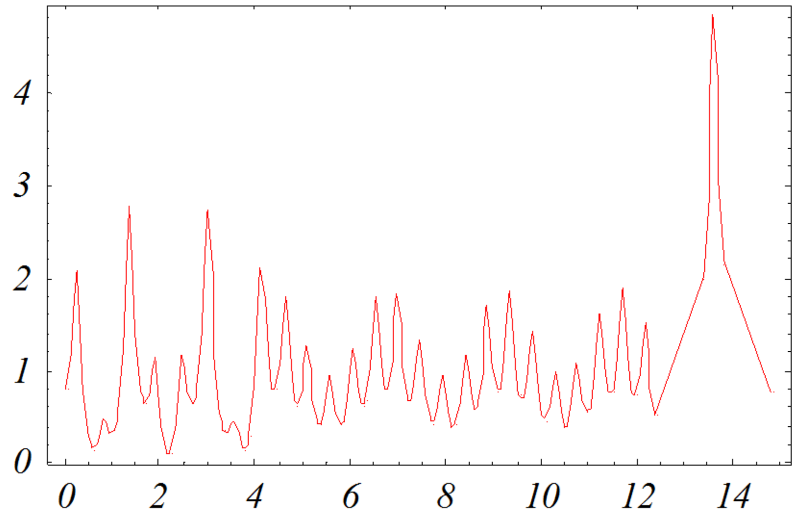
- Thanks to the tour at FFAG’14, we saw possibly the high-tech capability to produce a prototype magnet at BNL.

Beta Functions



Horizontal

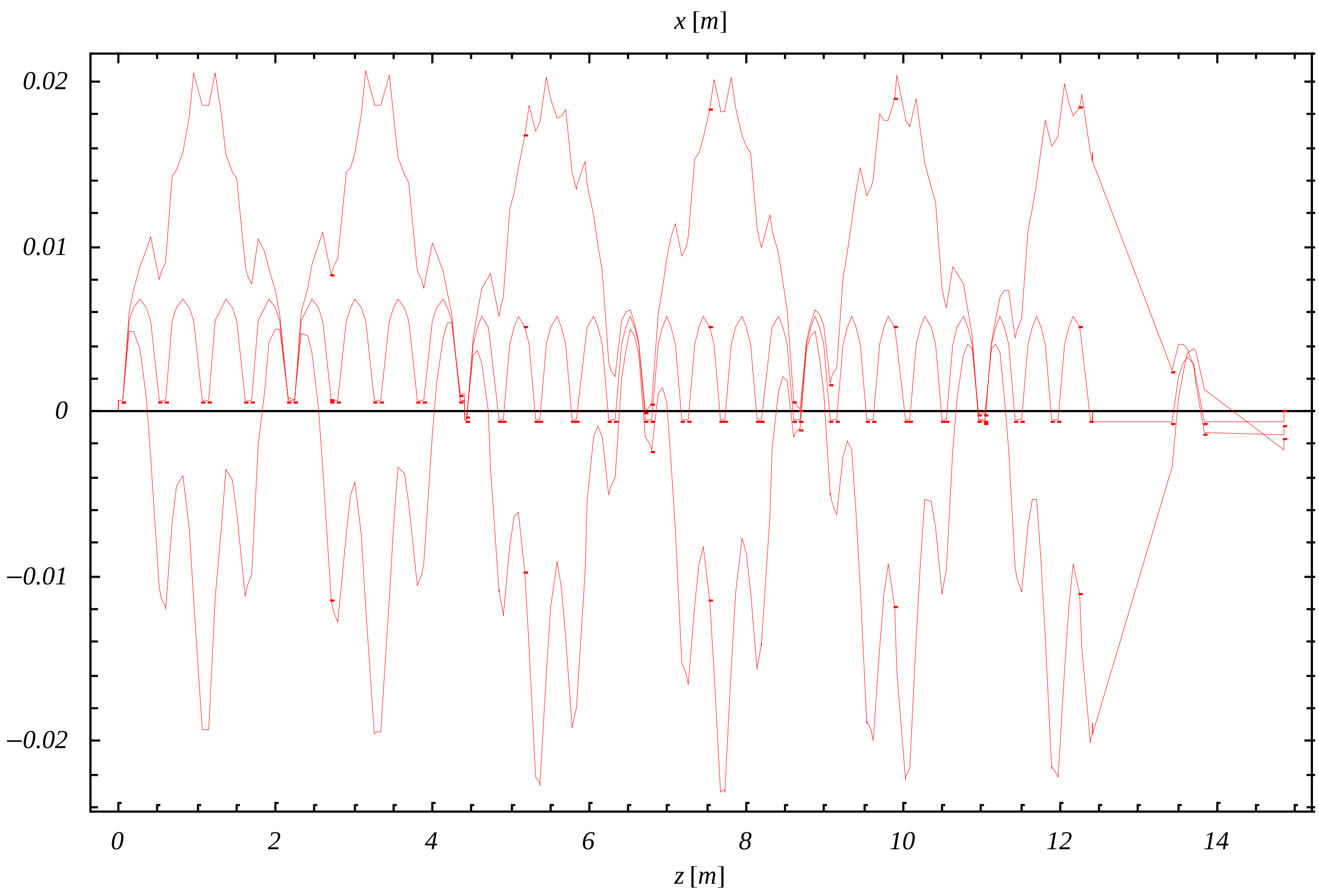
Initial and
final conditions
are reproduced!



Vertical

S,m

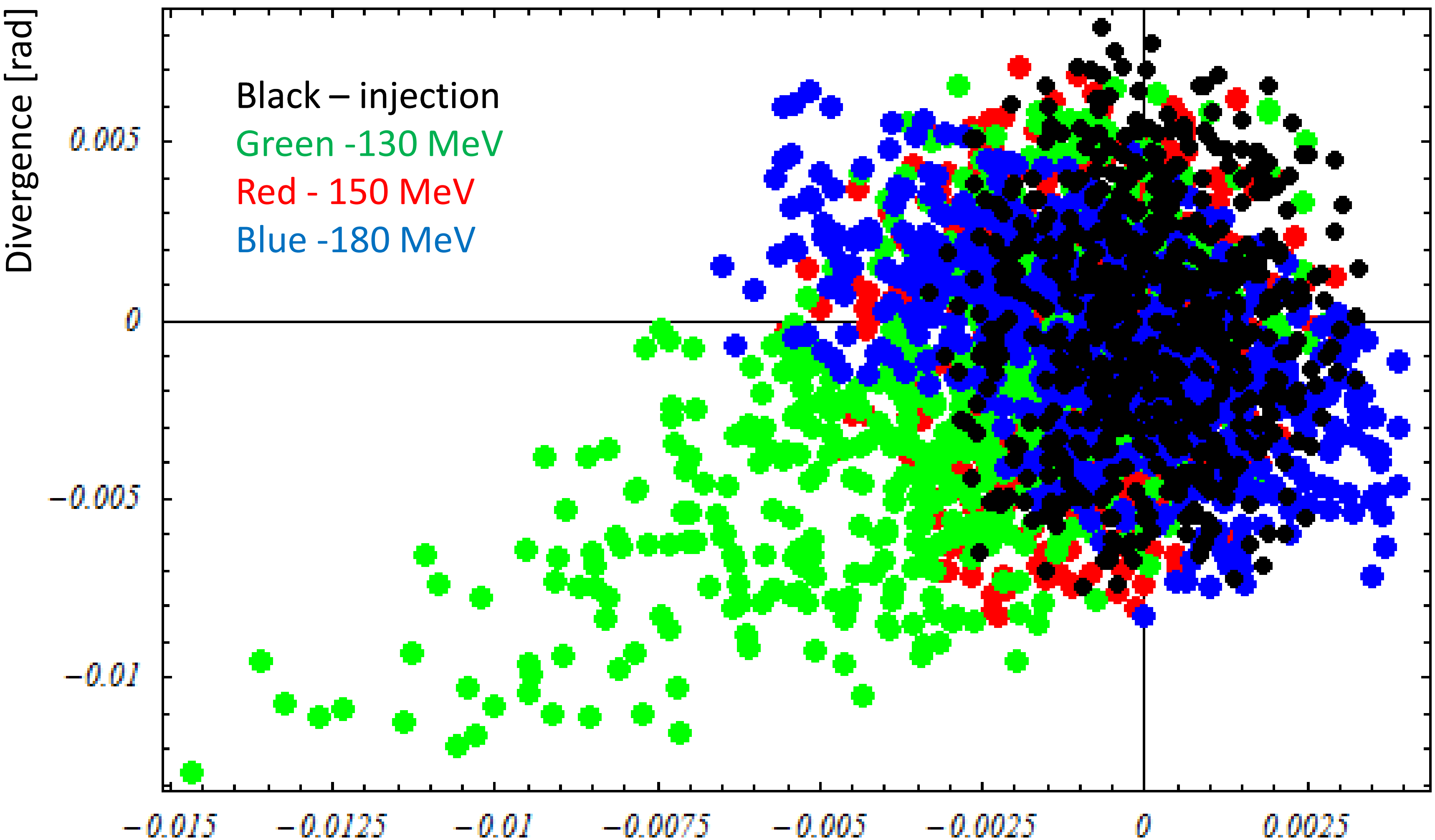
Horizontal orbits for 100,150 and 200 MeV



Dispersion matching seems to work!

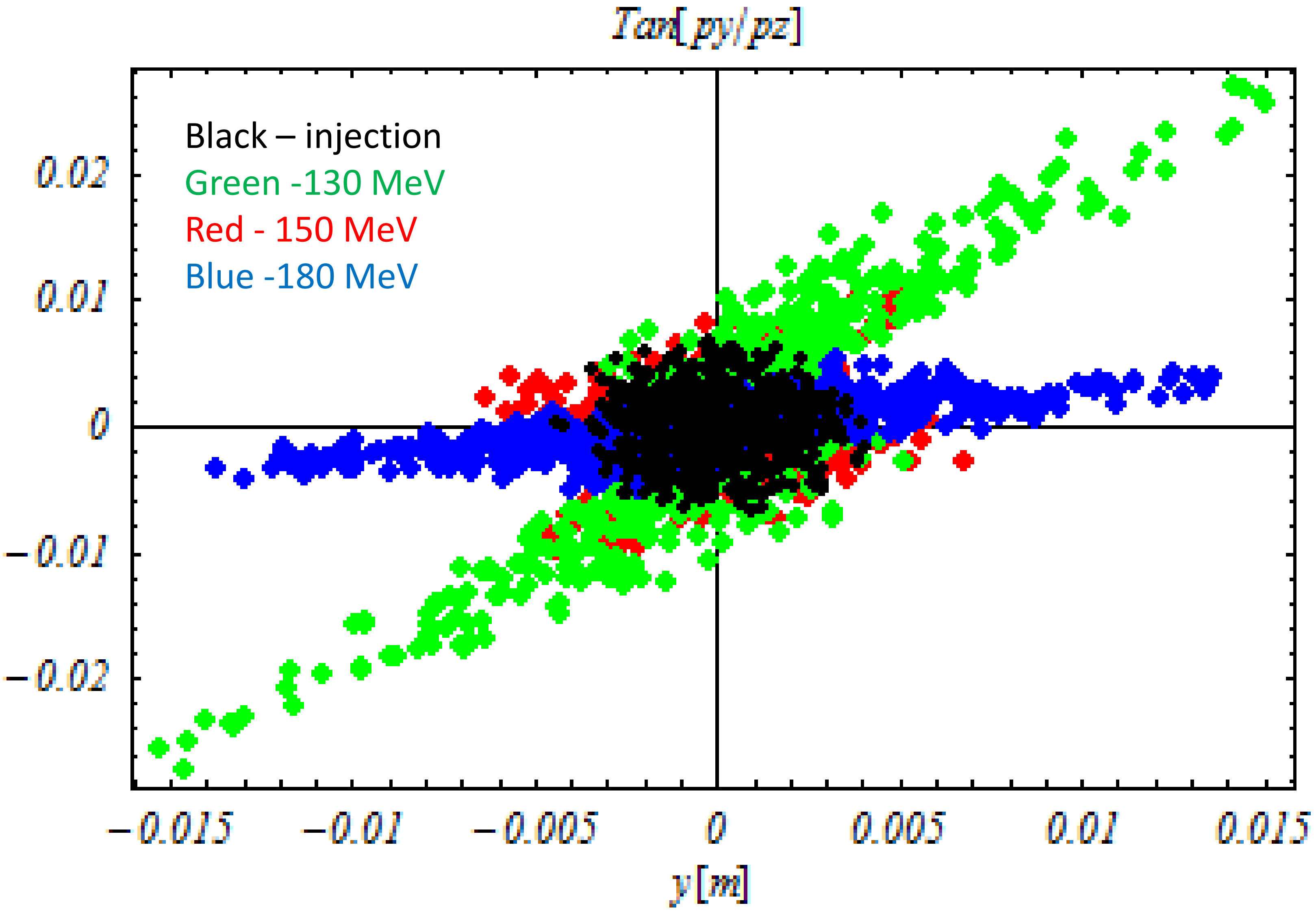
Tracking results at the patient's position

Zero dispersion seems to be working

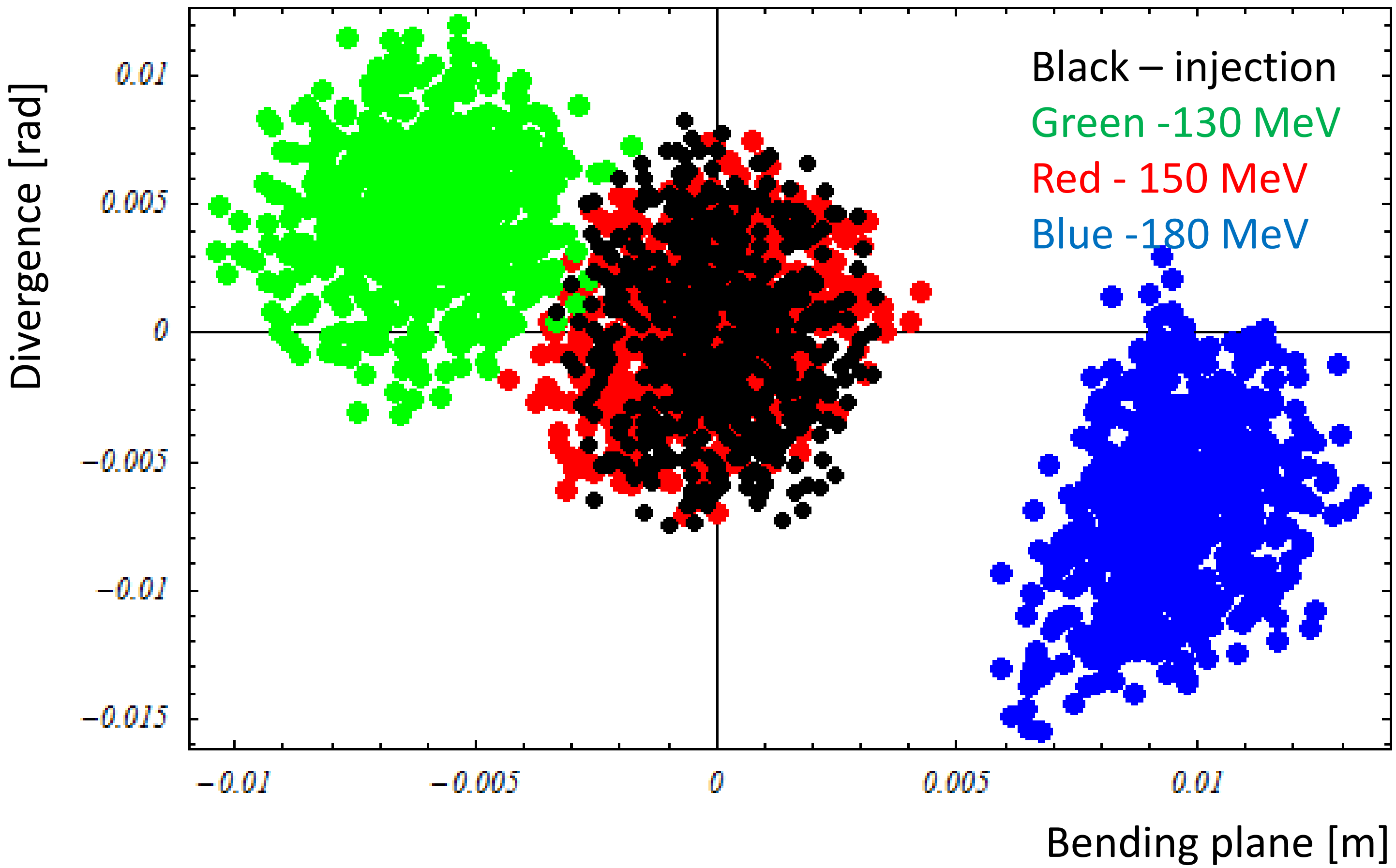


Some mismatch for higher amplitude particles!

There is a problem in non-bending plane

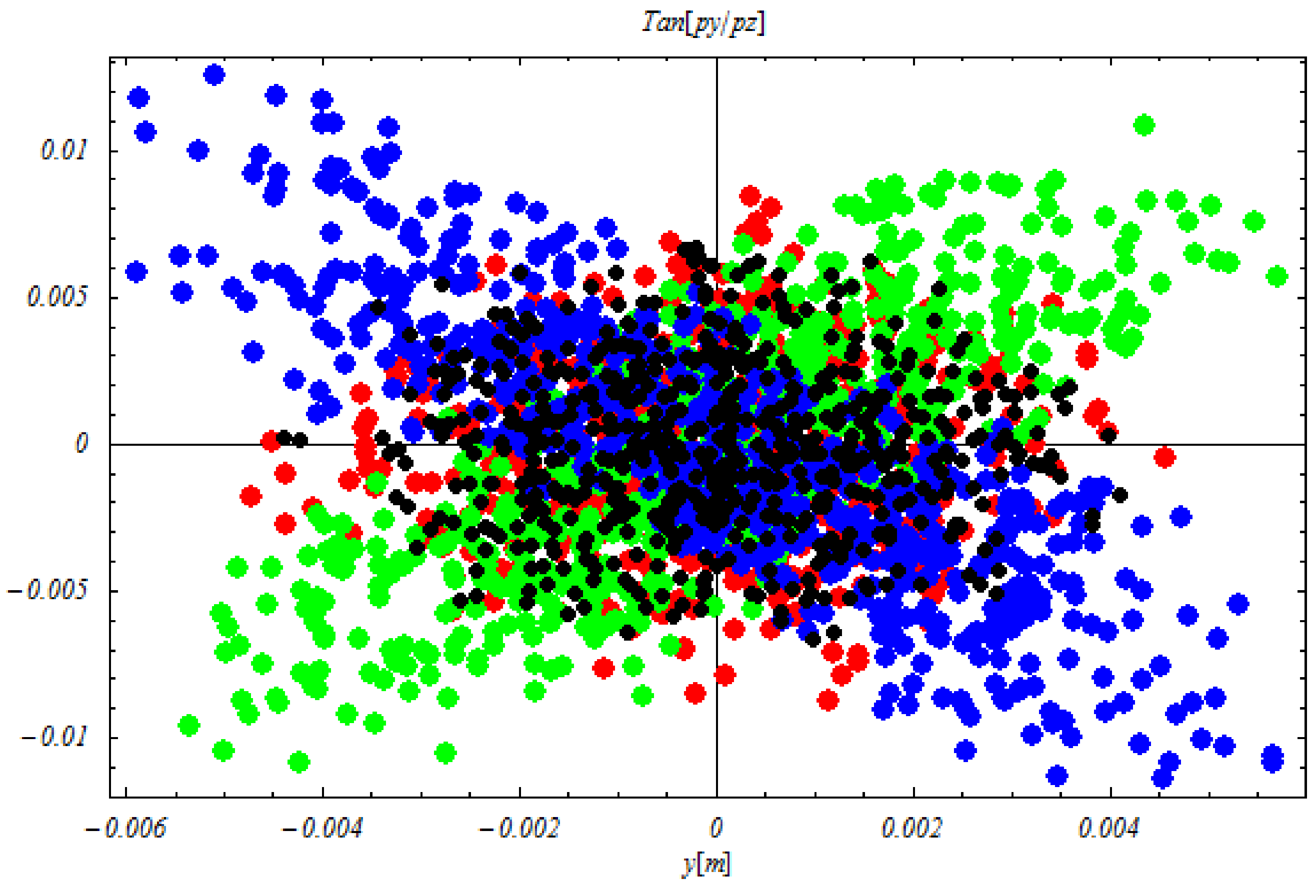


Results just before the final cell, Bending plane



You do not expect beams to have zero dispersion or the same beta here!

Results just before the final cell, non-bending plane



It looks, that the choice of the working point in the second half of the gantry needs to be improved, but mostly the large beta in the final cell is responsible for majority of the problem!

Conclusions for NL-NS-FFAG gantry

- NL-NS-FFAG solution can be made zero-chromatic.
- Nontrivial matching conditions can be made.
- Gantry shows promising results except the final cell, which needs to be improved.
- The choice of the working point in the second part of the gantry needs to be optimised together with the final cell.

Future work

- Improve the zero-chromatic procedure further.
- Optimise the working point in the second half
- Find alternative solution for the final cell.
- Find a path towards a design of the prototype magnet
- Building a prototype magnet would be great...